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Wind Power Quality Test for Comparison of Power Quality Standards

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WIND TURBINE POWER QUALITY TEST FOR COMPARISON OF POWER QUALITY STANDARDS

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Abstract

Power quality testing is important to wind power applications for several reasons. The nature of wind turbine generation is different from conventional power plants. Although windfarms are growing in capacity and diversifying in nature in the U.S. and throughout the globe, there is no standard that addresses the power quality of wind turbines or wind farms. The International Electrotechnical Committee (IEC) has convened Working Group 10 (WG10) to address testing and assessment of power quality characteristics of wind turbines. A IEEE task force has been appointed to reconsider flicker measurement procedures in the U.S. Lastly, power quality tests are now required as part of the certification process for wind turbines. NREL began this work both in response to industry request and in support of the IEC working group. (Mr. Gregory is a member of the IEC working group) This paper presents the NREL Certification Testing Team's effort in developing procedures and equipment for power quality testing for wind turbine certification. Summaries of several power quality standards that are applicable to this process are also presented in this paper.

Introduction

Power quality testing measures the impact of a device's electrical loading on the voltage at the point of utility connection. The importance of such testing is increasing as more wind turbines are being placed into service and diversify in technology, operational strategy and size. The formation of a new international standard on wind turbine power quality further indicates the importance of proper assessment of the impact of the wind turbine generation on the utility. This new standard (IEC CD), which when completed will be designated IEC Standard 61400-21, is at the committee draft stage. Currently, only general information on this standard is available to the public[1]. The IEC CD could potentially become an international standard for power quality measurement of wind turbines by the end of 1999.

Presently, there is no single recommended practice or standard governing testing for wind turbine power quality. Current U.S. practices require adherence to IEEE-519, published by the Institute of Electrical and Electronics Engineers (IEEE)[2] which is a current ANSI standard oriented towards steady electrical system loads. A study commissioned by the International Energy Agency (IEA) providing procedures specific to wind turbines is referenced[3] to lend additional background to this work. Also referenced is the IEC CD so NREL could establish a report format to satisfy the requirements of this document, should it become a standard.

This paper discusses four characteristics concerning the quality of power from wind turbines:

- Rated power
- Reactive power requirements
- Voltage variations, or Flicker
- Harmonic emissions

Test Description

Tests were conducted at a windfarm with minimal disturbance to normal operations. The tests were conducted at the request of the turbine manufacturer so the results have been normalized to protect the confidentiality of this agreement with NREL. The configuration of the test instruments is specified in Figure 1. Data sets were examined by an NREL engineer when collected for quality assurance purposes, then transferred to high-density storage media. Analysis was done after the field testing campaign was completed.

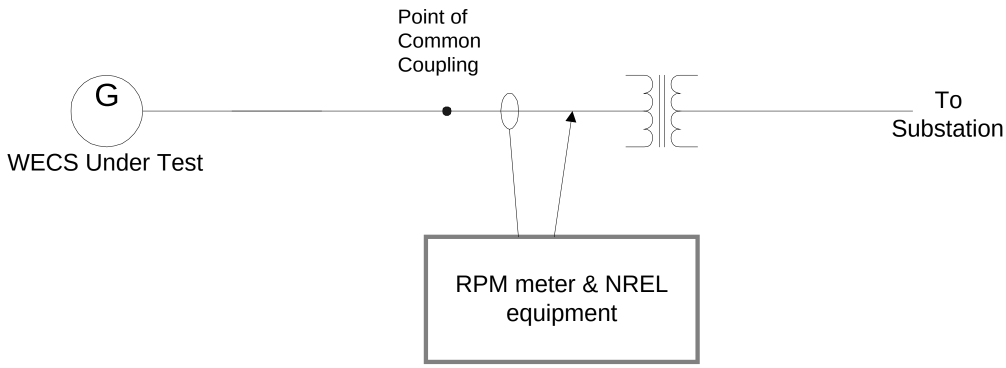

Figure 1: One-line diagram of test environment

A Reliable Power Meters (RPM) power recorder, running applications software suitable for power quality analysis, provided hourly summary reports. Additionally, NREL constructed a network of transducers, monitored by laptop data acquisition hardware, that provided individual waveform data.

While we could make a case for defining the Point of Common Coupling (PCC) on the distribution side of the transformer, available equipment determined the PCC measurement point as shown in Figure 1. The choice of this point is non-trivial (as certain quality effects may be modified by the transformer), yet the IEC CD is the only referenced document that provides objective criteria for equipment placement.

Discussion of Analysis and Results

<u>Rated Power</u>

Several power quality characteristics refer to the rated power of the wind turbine and it has general importance to sizing of the grid connection. Nevertheless, only the IEC CD provides objective criteria towards specifying this number. The IEC CD draws distinctions between reference power (determined from 10 minute-averaged calculations), maximum continuous power (defined as the maximum sustained power the turbine control system will allow), and maximum instantaneous apparent power. Typically, reference power has been defined as rated power, or generator nameplate power.

A wind turbine has a varied operating range where power output approximately increases with the cube of the wind speed until control actions limit that output. Many turbines have multi-valued power v. wind speed relationships, and many more vary in minute ways as the wind changes over the rotor plane. The proper technique for evaluating rated power suggested by the IEC CD is to find the maximum value of the power curve as determined by the IEC procedure for establishing wind turbine power performance[4]. This paper therefore uses the “reference power” from Figure 2.

<u>Reactive Power</u>

Proper determination of the turbine’s reactive power characteristics will allow the utility distribution engineer to plan for the impact on the steady state voltage over a range of wind speed conditions. The IEA document[3] includes a procedure involving estimating this impact on the distribution voltage by estimating grid impedances and measurement of turbine output real and reactive power. This procedure of calculating voltage variations amounts to a simplified load flow calculation, and is outdated by currently available PC-based load flow software.

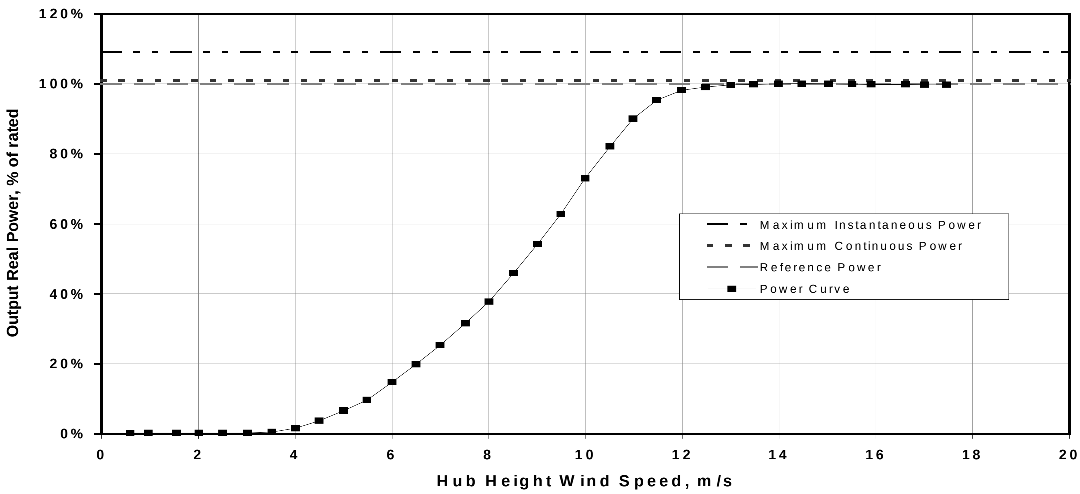

Figure 2 – Normalized WECS power curve

The IEC CD document also addresses reactive power, but sets no requirements or limits. Since wind turbines don't often produce power at one operating point for long, useful reporting of reactive power requirements involves correlating reactive power to real power. Most turbines use induction generators, almost all come equipped with power factor correction equipment, and the IEC document clearly includes such equipment in any measurement campaign. Many new turbine designs involve the use of an electronic variable speed drive, which may produce or consume reactive power depending on design and operating strategy. The reactive power output of the wind turbine tested is shown in Figure 3, as per the requirements of the IEC CD. Note that both real and reactive power are defined as positive when the turbine is providing power to the grid, and negative when the turbine is absorbing power from the grid. In this case, the turbine is providing real power and absorbing reactive power (inductive).

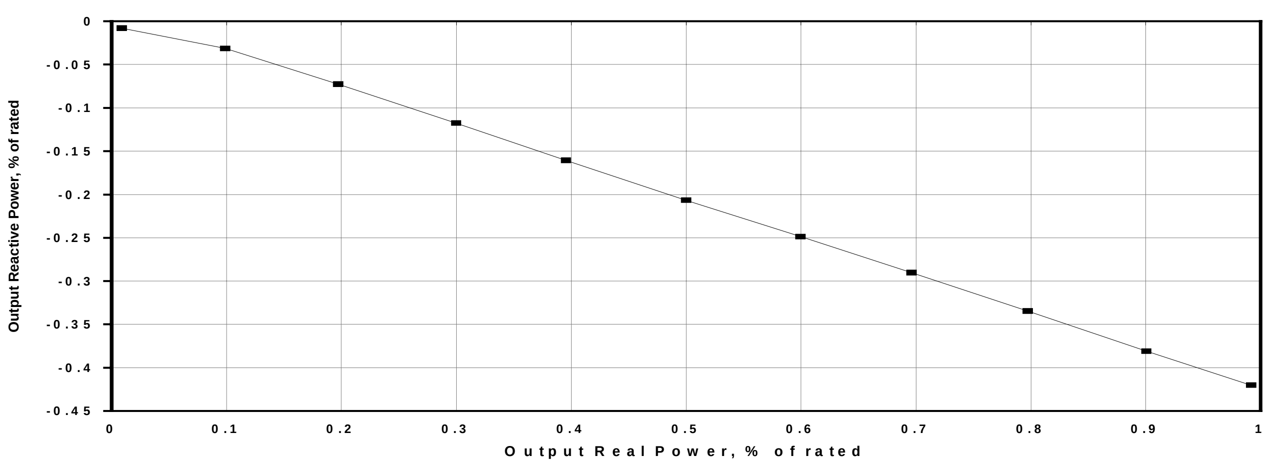

Figure 3 – Reactive power demand, normalized to rated power

Harmonic Emissions

Harmonic emissions from generators need to be controlled to prevent excessive heating in power distribution equipment and to avoid system resonance conditions. Harmonic emissions from wind turbines should be referenced by machine rating for proper analysis and comparison, as explained in the section on rated power. IEEE-519 and the IEC CD specify similar emissions limits, but the measurement techniques are different.

IEEE-519 requires that the device tested doesn't violate certain limits, but many of the criteria are either subjective, not suited to modern measuring equipment, or open to interpretation. Section 10.3 of IEEE-519 specifies that demand current (I_D) be assessed (without stating an assessment procedure) on 15 or 30 minute intervals. I_D shall be used as a modifier to the current total harmonic distortion (THD) to calculate the current total demand distortion (TDD) by TDD = THD*($I_{fundamental}$/ I_D), where $I_{fundamental}$ is the magnitude of the first harmonic for each data point. IEEE-519 specified, for generation equipment, that the TDD be less than 5%, but allows equipment operations lasting for less than one hour to exceed limits by 50%.

Since I_D is ambiguous and wind turbines rarely stay at one operating point for any length of time, these calculations can lead to abuse. It is noted that these limitations have not significantly limited applying the standard in the U.S. The normalized TDD v. real power is plotted in Figure 4. In this case, I_D was the phase current calculated from turbine's rated power. This should provide for a conservative reporting technique compared to the IEEE-519 procedure that load current should be based on a 12 month maximum, which would likely be greater than the turbine's reference power.

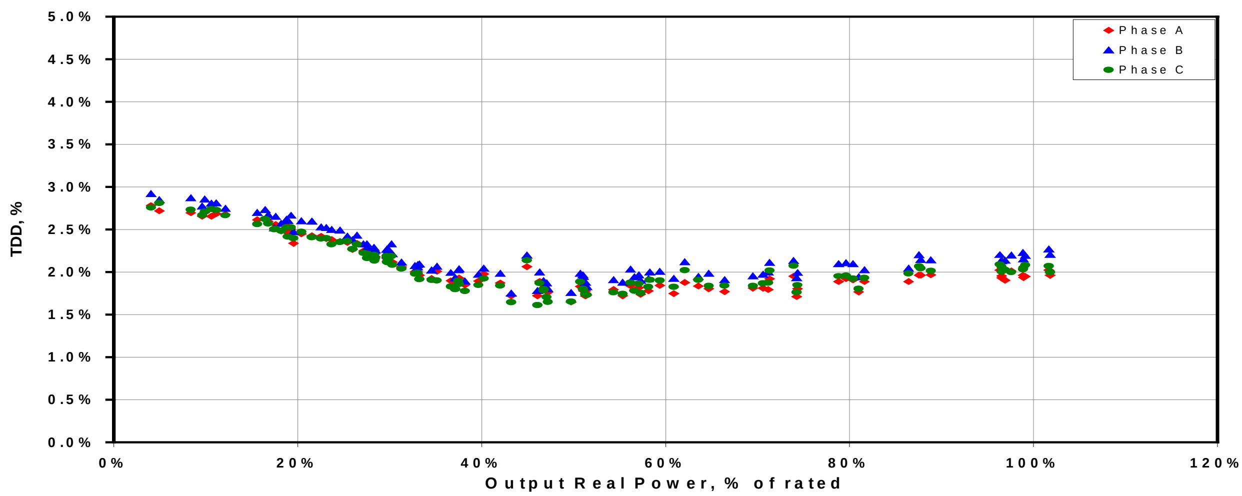

Figure 4: Current Demand Distortion (TDD) v. Normalized Output

Figure 4 shows the wind turbine tested to operate well below the maximum allowable TDD of 5%.

The IEC CD requires more detailed measurement techniques[6], and requires a long report listing the maximum current value for each harmonic order, along with the power output when that harmonic maximum was observed. The turbine's harmonics emissions are listed per the reporting technique in Table 1, where the output power is normalized by the turbine's rated power and the harmonic current is normalized by the phase current at rated power (I_{ref}). It can be seen that the turbine exceeds the emission limits dictated by the IEC procedure on several harmonic orders, as well as the maximum THD. Values of

THD (THD = square-root of the sum of squares of the amplitudes of all harmonic currents divided by the magnitude of the fundamental current) were found for every dataset taken, and the maximum THD of any dataset was reported. Note that this procedure was calculated from a single-phase measurement, based on expediency. Figure 4 shows the phases to be in close agreement, such that the required three-phase measurement will not vary greatly from a single-phase measurement.

Order	Output Power (% of rated)	Harmonic Current (% of Iref)	Order	Output Power (% of rated)	Harmonic Current (% of Iref)
2	99.1%	0.3%	3	19.1%	0.4%
4	5.4%	0.3%	5	30.7%	0.4%
6	96.3%	0.2%	7	48.8%	0.2%
8	96.5%	0.2%	9	5.4%	0.1%
10	4.4%	0.2%	11	5.4%	0.5%
12	19.1%	0.7%	13	32.4%	0.6%
14	101.8%	0.9%	15	58.3%	0.9%
16	4.4%	2.0%	17	18.2%	1.1%
18	69.5%	0.9%	19	101.8%	0.8%
20	58.3%	0.4%	21	101.8%	0.5%
22	5.4%	0.1%	23	98.9%	0.1%
24	-	0.0%	25	96.3%	0.1%
26	97.6%	0.1%	27	69.5%	0.1%
28	26.7%	0.1%	29	5.4%	0.1%
30	35.9%	0.2%	31	29.9%	0.4%
32	37.5%	0.8%	33	35.9%	0.4%
34	40.3%	0.8%	35	36.1%	0.3%
36	5.4%	0.1%	37	28.7%	0.1%
38	11.5%	0.1%	39	-	0.0%
40	29.9%	0.1%	41	-	0.0%
42	-	0.0%	43	-	0.0%
44	-	0.0%	45	-	0.0%
46	-	0.0%	47	5.4%	0.2%
48	29.9%	0.1%	49	29.9%	0.2%
50	35.9%	0.1%			
Maximum Total Harmonic Current Distortion (% of Iref):					69.21%
Output Power at Maximum Total Harmonic Current Distortion (kW):					32.97

Table 1 – Maximum current harmonic emissions by order per IEC procedure

Flicker

Voltage fluctuations roughly between 0.5 and 25 Hz that cause visible variations in domestic lighting are termed "flicker." These fluctuations and their characteristics have been thoroughly studied in Europe including efforts in adapting flicker estimation techniques to the characteristics of wind power[7]. IEEE-519 uses a graphical technique, plotting severity of disturbances in per cent versus the frequency of disturbances. The assessment procedure for this technique is based on studies over 65 years old, and takes no account of modern power modulation techniques.

The procedure in IEEE-519 is rarely supported by currently available power analysis and recording equipment. Many modern power analysers cite adherence to "IEC flicker procedures" but fail to define which of the procedures are followed, or which type of measurement campaign (short term or long term) is assessed. IEEE Voltage Flicker Task Force P1453 is currently considering adopting the IEC flickermeter standard[8] for a measurement specification, but has not indicated a standard for specifying emission limits. Consequently, NREL's work will not attempt to present results from the IEEE-519 flicker assessment procedure.

The IEC CD has modified the standard flicker procedures[9,10] to be more applicable to the special characteristics of wind turbines. This involves calculating flicker coefficients based upon the measured output current of the turbine and theoretical grid conditions. (coefficients of flicker are based on "units of perception", where a value of 1.0 is the point where 50% of average people will become irritated by flicker in an incandescent light) The IEC CD procedure avoids having measurements affected by other devices or background voltage conditions, but has significantly increased the difficulty of this calculation. The exact requirements for the flicker assessment procedure contained in the IEC CD have not been finalised. NREL is currently establishing the data analysis techniques necessary to conduct this procedure as proposed in the IEC CD document. In the future, NREL would like to answer two fundamental questions about the IEC flicker assessment procedure:

- Does a flicker coefficient of 1.0 lead to complaints from modern households?
- Does a flicker emission limit of $E_{p,lt} \leq 0.7$[10] present a burden to WECS design and operation?

Conclusions

Careful examination of the IEC CD and IEEE-519 (as applied to wind turbines) have found ambiguous and differing requirements. Four turbine characteristics that are addressed in at least one of these documents have been detailed. The turbine tested for this paper is compliant to the U.S. standard for power quality characteristics, but not to the harmonic emission limits proposed by the IEC CD.

Power quality characteristics of loads and generation equipment are changing faster than the standards. This is quite evident when applying the IEEE-519 standard to wind turbines.

Overall, IEC WG10 and the IEEE are now approaching flicker assessment in a way which will bring the procedures up to date. The IEC CD document has approached several issues more relevant in modern wind plant applications, and will provide for a good reference document even if it is not approved as a standard.

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